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Augmentation of Natural Populations of Entomophagous Insects Through the Use of Secondary Food Sources

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Title of Senior Thesis Project:

Augmentation of Natural Populations of Entomophagous Insects Through the Use of Secondary Food Sources

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Abstract

Local densities of predators, including ladybeetles, parasitoids, big-eyed bugs, and minute pirate bugs, increased with the application of artificial honeydew to alfalfa in late summer in northern Utah. The artificial honeydew consisted of sugar and wheast dissolved in water. Sugar, rather than wheast, was the active ingredient causing predators to aggregate, although wheast prolonged the effect of the sugar treatment for the ladybeetles. Furthermore, the artificial honeydew treatments had a marked effect for a period of one week. These results suggest a potentially important role of the use of synthetic honeydew as a means of pest control in an Integrated Pest Management system.

Introduction

The Practice and Theory of Biological Control

With the advent of vast monoculture farms, pests that compete directly with humans for food have become an increasing problem (Miller 1991). Chemical pesticides were developed and came into heavy use after World War II. Initially, these pesticides were regarded as a cheap panacea for all pest problems. Biological control, which came into wide use in the United States in the 1880s with the introduction of the vedalia beetle to control the cottony-cushion scale, fell out of use. Today, because environmental pollution looms as a national and world wide problem, unrestricted use of agricultural chemical agents, which are a major source of environmental contamination, has been reevaluated. Biological control, the utilization of the natural enemies of weeds and pestiferous insects to reduce damage to economically important crops, has reemerged as a vital component in integrated pest management programs designed to reduce the use of chemical pesticides.

The central concept of biological control is based on the ecological principle that in diverse ecosystems pests are kept in check by natural predators. Biological control was formally defined by DeBach (1964) "as the suppression of a pest by means of the introduction, propagation, and dissemination of the predators, the parasites, and the diseases by which it is attacked." The aim is to use natural predator/prey interactions to maintain pest densities below a level where they would inflict economic loss.

Environmental contamination is not the only impetus behind the implementation of biological control. Many problems that arise due to the unrestrained use of chemical pesticides can be avoided by enlisting beneficial agents in pest control. Ideally, the predators become a part of the ecosystem. Furthermore, the target pests do not become resistant to the predators as they do to chemical pesticides; as the pest responds to natural selection and evolves in response to the predator, the predator also evolves. This can save millions of dollars in research into new pesticides that are required to kill resistant super-pests (Huffaker et al. 1976, and Miller. 1991).

Some chemical pesticides kill a broad range of organisms including non-target organisms. Often the non-target organisms are populations of beneficial, natural predators. Populations of pest species may rebound in the absence of predators to even greater densities than before. These secondary resurgences of pests create a dependence on the use of pesticides (Miller 1991).

Unlike chemical pesticides, biological control can be self-sustaining and often does not need to reapplied year after year. The predator and the prey may interact in a density dependent manner. In short, as pest numbers increase, predators increase in numbers or efficiency, acting to drive pest density down (Huffaker et al. 1976, and Miller 1991). Economically, biological control makes sense. Estimates of returns per unit cost from biological control range around 30 to 1 due to savings in reduced pest damage and treatment costs. In isolated examples, the return benefits are much higher. On the other hand, pesticide companies estimate a return of five dollars for every dollar invested in chemical pesticides (Van Lenteren 1980).

Biological control alone is not the answer to pest problems, but it could reduce dependence on pesticides if it were used in conjunction with other nonchemical methods of pest control. Any reduction in the amount of chemical pesticide sprayed per year significantly decreases the amount of money spent on pest control.

Many of the most damaging pests and weeds have been introduced from other geographical regions. Since non-native pests, especially weeds, are often consumed to only a low degree by indigenous predators, they proliferate, out-compete native organisms, and cause significant damage (Harris 1988). Consequently, the greatest successes in biological control typically have resulted from the importation of predator and parasite species, as was the case with the parasitic wasp, Bathyplectes curculionis (Hymenoptera: Ichneumonidae), that lays its eggs in alfalfa weevil larvae. The alfalfa weevil was accidentally to Utah in 1904. The parasitic wasp was imported ten years later to attack the weevil; both weevil and wasp are native to Europe.

Since its inception, much has been learned about biological control. However, theory as yet is not able to reliably predict which species will be effective as control agents (Van Lenteren 1980). Trial and error still plays the main role in the selection of natural enemies. Intuitively, the best control agent would be the one most closely adapted to its host. It would be able to spread throughout the host range and be capable of establishing a low but stable pest equilibrium (Van Lenteren 1980). Case studies have shown that many successful control agents possess the following properties: high host specificity, synchronization with host, direct density dependence (density increases as pest density increases), high search capacity, ability to survive periodic absence of host, and aggregation in areas of high pest density (Van Lenteren, 1980). These characteristics are more typical of specialized predators such as parasitoids. Hence, general predators, which do not demonstrate the above characteristics, have been neglected as biological control agents. However, the use of general predators to induce local pest extinction has been presented as an alternative to the classical use of parasitoids which establish low but stable pest densities (Murdoch et al., 1985).

Augmentation of Biological Control Agents

In recent years research into the augmentation of the size or efficiency of already existing populations of natural enemies has been fruitful (Hagen 1986). Secondary food sources such as nectars, pollens, and honeydews have been implicated in bolstering populations of predators in the field in three ways. In some instances they function as a kairomone, a chemical homing device. It has been suggested that some predators can sense volatile chemicals which emanate from plants, many of which have been found in nectars, pollens, and honeydews. These chemicals help predators orient on their prey (Norland and Lewis 1976). Areas where secondary food sources that predators utilize is produced in large quantities might indicate high densities of its primary host species. In other cases the predator is arrested in its search for food. Over time, even though the predator is not attracted to the site, the arrestant activity of the secondary food source causes large numbers of predators to aggregate (Hagen et al. 1976). Finally, the predator may use the secondary food as a source of energy. Research indicates that these food sources contain limiting nutrients that are not present in their regular prey items. The energy or nutrients obtained from the secondary food source can sustain predator populations during periods of low prey density and can even induce the predator to lay eggs earlier in the season (Hagen et al. 1971). These three factors have a cumulative result of aggregating large numbers of predators so as to prevent the pest from reaching outbreak levels and damaging crops.

Much of the seminal work in the use of secondary food substances centered around mimicking the honeydew produced by aphids. Aphid feeds by piercing the phloem of plants and feeding on the sugar rich fluid. Aphids extract the limiting nutrient, nitrogen, from the sap and excrete unused material. The excreant, rich in carbohydrates and amino acids, is honeydew. Hagen et al. (1971) demonstrated that high aphid numbers could be simulated by the application of a solution of common table sugar and wheast, a biological extract of yeast. Hagen et al. (1976) also demonstrated that the artificial honeydew acted to aggregate high numbers of general predators such as ladybeetles and lacewings. An artificial honeydew composed of a solution of sugar and wheast, a protein extract from yeast, was found to be most effective. Tryptophan, an amino acid present in the wheast, was implicated in attracting some predators (Hagen et al. 1976).

Objectives of the Present Study

I chose to study predator responses to artificial honeydew in alfalfa fields because alfalfa is an economically important crop in Utah and millions of dollars are lost across the state each year to damage from alfalfa weevil larvae and other pests. Preliminary work in the spring of 1991 that I participated in under the direction of Dr. Edward Evans indicated that natural enemies of the alfalfa weevil, including parasitic wasps, aggregated in response to a synthetic honeydew spray similar to those used by Hagen and others (Hagen 1986). If existing predators populations could be augmented through the use of artificial honeydew, pest damage might be reduced. Whether these food sources can be utilized as feasible means of controlling agricultural pests is an important question. My study was designed to follow up on these preliminary results. The project had two main objectives: (1) to determine which component of the artificial honeydew spray, sugar or wheast (a yeast by-product), is the active ingredient in attracting predators, and (2) to determine how the effects of the spray decay over time.

Materials and Methods

The study was conducted August 10-23 1991, in an alfalfa field farmed by Utah State University in Logan, Utah. The alfalfa was in its third growing season and had already been cut twice earlier in that season, in late May and in mid-July. Except for the west end of the field where grasses and other weeds were present, the alfalfa grew as a thick stand; it stood 30-40 cm high in mid-August. The height of the stand did not change appreciably over the ten day period of the study.

Twenty-four plots were laid out toward the northern end of the field in an east-west orientation in four rows of six plots each (Figure 1). The rectangular plots were 12 meters (along the western and eastern borders) by 10 meters, with a 10 meter border between plots. Colored flags marked the corners of each plot. The field was divided into an eastern and western block each comprised of twelve plots to compensate for any spatial variability in the plant and/or insect community. Each plot within the blocks was assigned randomly to one of four treatments: a solution of Sugar, Wheast, or Sugar @ Wheast dissolved in water, or water alone was applied to a given plot (Figure 1). The sugar and wheast, a protein extract from yeast, were mixed together to serve as an artificial substitute for aphid honeydew (Hagen et al. 1971). They were also applied separately to determine whether each contributed in causing the predator species to aggregate. They were applied together to see if there was a synergistic interaction. The water was used as a control treatment.

Each plot was treated with 1.5 liters of one of the four solutions using a hand sprayer on the morning of August 13 from 10:00 am to 12:30 pm. Solutions were prepared just before spraying by dissolving 75 grams of common table sugar and/or 75 grams of Wheast in 1.5 liters of water.

The plots were then sampled with a canvas sweep net on August 14, 15, 17, 20, and 23 (i.e., days 1, 2, 4, 7, and 10 after the treatments were applied). On each occasion the plots were sampled by taking 15 sweeps through the vegetation. A 180 degree arc through the upper canopy of the alfalfa was taken at each step. After each set of 15 sweeps, the contents of the net were transferred to a plastic bag, labeled and frozen. The samples were always taken between 10:00 and 11:30 am on warm days (around 25 degrees Celsius by noon) with 40% or less cloud cover and light breezes. It rained lightly in the afternoon on August 16, but the moisture had dried off by the next morning. There was no other precipitation during the period of the experiment. Sweeps on the first day after treatment, August 14, were taken along a south-north transect through the eastern side of each plot. Successive samples thereafter were rotated, with sweeps taken from the middle, western and back to the eastern section of each plot in a attempt to minimize the disruption of the insect community.

Predators from each sample were identified in the lab to family (individuals belonging to different species within families were pooled). I distinguished between three groups of general predators: ladybeetles (Coleoptera: Coccinellidae), big-eyed bugs (Hemiptera: Lygaeidae, Geocorinae), and minute pirate bugs (Hemiptera: Anthocoridae). In addition, I focused on parasitoid wasps (Hymenoptera: various families), specialized predators that lay their eggs in the larvae of insect host species. I also counted the number of pea aphids (Homoptera: Aphididae). The data (number of predators of a given group) were analyzed using a complete randomized block analysis of variance (RCB ANOVA) with repeated measures. Analyses were performed using SAS, version 5.0 Proc GLM.

Results

The artificial honeydew was intended to simulate high densities of aphids. I therefore hypothesized that predators that either utilize honeydew as a secondary food source or feed directly on aphids would aggregate in higher densities in sugar*wheast plots, as has been demonstrated in previous studies (Hagen 1986). If indeed this hypothesis is supported, it is important to determine whether just one or both of the two ingredients is the active ingredient. I therefore tested for a significant difference between the sugar solution treatment and the wheast solution treatment. Over the course of the experiment, I monitored aphid densities in the control plots because Hagen et al. (1976) demonstrated that high background levels of aphids confounded results from using artificial honeydews. Mean densities of aphids in the control plots were low throughout the study, with no more than a slight downward trend over time (Figure 2). The responses of each group of predators to the experimental treatments will be considered individually.

Ladybeetles.

Ladybeetles were common in the study plots during the first half of the experiment. Even though aphid densities did not change appreciably in the control plots over the course of the experiment, numbers of ladybeetles declined sharply throughout the field between days 4 and 7 following spraying. By day 7 very few ladybeetles were collected from any of the plots: an average of two ladybeetles per plot was collected in the sugar*wheast plots, only one ladybeetle per plot was collected in the sugar plots, and less than one ladybeetle per plot was collected in the Wheast and control plots combined. Therefore, for ladybeetles, only data through day 4 will be analyzed and discussed.

Ladybeetles responded strongly to both the sugar*wheast treatment and to the sugar treatment within 24 hours after application, achieving densities ten times those in plots treated with wheast or water alone (Figure 3). Wheast alone was indistinguishable from the control treatment of water alone throughout the experiment. Interestingly, the response of ladybeetles to the sugar*wheast solution remained constant over the first four days after spraying, while the numbers of ladybeetles in the Sugar plots deteriorated markedly from day 1 to day 4 (Figure 3; See statistical results for interaction with date in Table 1). In summary, ladybeetles increased significantly in response to sugar (Table 1). When (but only when) sugar was present, the addition of wheast increased the effectiveness of the artificial honeydew in maintaining high local densities of ladybeetles (this result is reflected in the significant sugar*wheast interaction as shown in Table 1). Thus, even though the ladybeetles did not respond to wheast when applied alone, wheast somehow was involved in prolonging the effect of the sugar. The simplest explanation for this result would be that the wheast was acting as a coagulant that prevented the sugar from washing off the alfalfa. Alternatively, the wheast might provide some limiting nutrient which only becomes a factor with time in the presence of sugar. Even though natural honeydews do not contain all ten essential amino acids, they do provide some of the essential amino acids for the insects that do feed on them. Artificial honeydew composed of sugar only would provide none of these amino acids (it would provide only a carbohydrate energy source) and, over time, insects might need to find a source of these necessary nutrients.

Parasitoids.

The densities of parasitoids on the plots and their differential responses to the treatments varied significantly over time (see significant date*sugar and date*wheast interactions in Table 2). These complicated responses arise largely because the analysis included data through Day 7, when virtually all distinguishable effects of the treatment had disappeared. That is, the original effect of the treatment was allowed to decay over time. However, the interactions of sugar and wheast with date should not hamper the interpretation of the response of the parasitoids to the sugar treatment or the sugar*wheast treatment because immediate and strong. The interaction plots of the parasitoids showed a trend similar to that of the ladybeetles in that any treatment involving sugar caused large numbers of parasitoids to aggregate, but the divergence over time between the Sugar and the sugar*wheast treatments was absent. Sugar*wheast plots consistently showed fewer parasitoids and took longer to build up to peak levels that did plots with sugar alone accounting for the sugar*wheast interaction (Table 2). A treatment of Wheast alone elicited a response that was indistinguishable from the control treatment of water. Sugar caused a significant increase in parasitoid numbers (Table 2), as illustrated in a plot of the number of parasitoids over time in the presence and absence of sugar (data combined from plots with and without wheast: Figure 4). The response on day 1 to sugar is immediate with nearly twice as many parasitoids found in sugar treated plots as in plots that had not been treated with sugar. Parasitoid numbers built up over time in the sugar treated plots (generating a date*sugar interaction; Table 2) to reach a peak by day 4 of nearly three times that of plots without sugar (Figure 4). Parasitoid numbers dwindled after day 4. The reason for a lag time in the build-up of parasitoid numbers which was not present in the ladybeetles is unclear. Differential mobility probably accounts for the difference. Ladybeetles are large and highly mobile predators. The majority of the parasitoids sampled were tiny in comparison and, likely, not as mobile over large distances, accounting for the delayed response.

Minute Pirate Bugs.

Responses of minute pirate bugs were also complicated by significant interactions sampling date with treatment (Table 3). These interaction arose again because treatment effects dissipated by Day 7. As with parasitoids, minute pirate bugs responded strongly to sugar but did not respond significantly to wheast alone (Table 3). The sugar*wheast interaction was marginally significant (Table 3). Comparison of the numbers of minute pirate bugs over time in the presence and absence of sugar reveals that by day 4 predator numbers in sugar treated plots peaked at twice those in plots without sugar. By day 7 the effect of sugar had diminished. By day 10 all plots are indistinguishable (Figure 5).

Big-eyed bugs.

Big-eyed bugs did not respond to wheast, nor was there any interaction of wheast with sugar and/or date (Table 4). The big-eyed bugs did, however, respond strongly to sugar and showed the same characteristic response to date and date*sugar interaction (Table 4). Comparison of big-eyed bug responses over time to the presence of sugar verses its absence shows twice as many predators in the sugar plots as in the non-sugar plots on day 1 (Figure 6). Again the response fell off by day 7 such that densities were indistinguishable in all plots.

Discussion

Clearly, sugar was the most influential ingredient in the artificial honeydew spray that I used. The study demonstrates that several families of predator respond to artificial honeydew by aggregating in higher densities in treated areas as if high densities of aphids were present. The peak average number of predators in the sugar treatment plots ranged between two, for big-eyed bugs, and ten, for ladybeetles, times greater than in the control plots or the plots with wheast alone. There were other responses such as to wheast, to date, and, except for big-eyed bugs, to a sugar*wheast interaction which complicated interpretation of the data and need to be more closely scrutinized when this experiment is repeated. Furthermore, the response to sugar had a definite half-life with the effect of the sugar wearing off between day 4 and day 7 in all groups.

These results could have interesting implications for biological control. Prior to this research and related research completed in the spring of 1991, a response by parasitoids to synthetic honeydews has only been documented for one species, a common parasitoid of syrphid larvae, Diplazon laetatorious (Hagen et al. 1971). The responses of minute pirate bugs and big-eyed bugs are of particular interest because they have not been previously shown to respond to a treatment of artificial honeydew (Hagen 1986). Since the groups of predators range from specialized feeders such as parasitoids to generalists such as the big-eyed bugs, it is hard to believe that they all orient to or utilize the sugar in the secondary food source in the same way. These results suggest far reaching implications concerning the insect biology of sugar. Polyphagous, general predators such as ladybeetles, big-eyed bugs, and minute pirate bugs might be switching over to the synthetic food in the absence of prey. Use of artificial honeydews to bolster general predators at critical times could serve as a tool to drive local pest densities to extinction or to low levels. These results with generalist predators challenge the age old doctrine of keeping low but stable pest densities through the use of specialized predators (Murdoch et al. 1985). Thus, more attention should be paid to general predators as viable biological control agents. The strong and rapid response of these polyphagous predators could be especially useful if certain critical times for pest control could be identified. Though specialist predators have been used extensively as a means to maintain low densities of pest in the field, possibly the response of general predators could be used as a back up to specialist predators in case of pest outbreaks.

The response of parasitoids is also of significance. It is a reasonable assumption that percent parasitism in the pest population would increase with higher densities of parasitoids. These results suggest that even lower pest equilibria than are now possible could be maintained though the augmentation of parasitoid populations.

The seven day efficacy of the treatment may indicate that even though predators utilize synthetic food sources, they can not subsist on them in the absence of prey indefinitely. Artificial honeydews probably do not provide all the nutrients necessary for life. The study plots contained low numbers of pea aphids throughout the experiment (Figure 2). The effect of the treatment might possibly have persisted longer if more prey items were available which would have provided a more balanced diet. Conversely, the results may simply indicate that the artificial honeydew wore away. The alfalfa should be sampled in a follow up experiment to determine whether any of the spray remains to settle this question.

The critical question of whether higher predator populations induced by synthetic food sources translate into reduced pest populations remains to be answered. Aphid populations have been reduced by such treatments (Hagen et al. 1971). Preliminary research by Dr. Edward Evans indicates that numbers of alfalfa weevils and pea aphids are reduced in Utah alfalfa fields by a regular treatment of synthetic honeydew. However, it is not yet clear whether the reduction results from higher numbers of general predators and/or by augmentation of a parasitoid predator of the weevil. Determination of the frequency of application of artificial honeydew required to reduce pest numbers remains unanswered. Because the spray is contains sugar, it probably would wash off in rain; this has important implications for the use of this non-chemical method of pest control in less arid environments that Utah. Initial studies into the augmentation of entomophagous insects through the use of secondary food sources show promise in enhancing biological control agents. However, as has been shown in this report, many questions remain to be answered before the usefulness of this non-chemical treatment as a means of pest control can be ascertained.

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Statistical Tables

Table 1. Ladybeetles sampled 14-17 August 1991. Data analyzed using complete randomized block analysis of variance (RCB ANOVA) with repeated measures from number of ladybeetles collected per 15 sweeps from sugar, wheast, sugar*wheast or control plots, 14-17 August 1991.

Ladybeetles

Source	df	MS	F Value	Pr
Block	1	0.013889	0.00	0.9844
Sugar	1	7708.680556	217.69	0.0001
Wheast	1	316.680556	8.94	0.0075
Sugar*Wheast	1	387.347222	10.94	0.0037
Error	19	35.411550		
Date	2	143.291667	3.38	0.0446
Error(D*B)	2	198.430556		
D*S	2	70.930556	1.67	0.2012
D*W	2	134.263889	3.17	0.0535
D*W*S	2	102.180556	2.41	0.1034
Error	38	42.398392		

Table 2. Parasitiods sampled 14-23 August 1991. Data analyzed using complete randomized block analysis of variance (RCB ANOVA) with repeated measures for the number of parasitoids collected per 15 sweeps from sugar, wheast, sugar*wheast or control plots, 14-23 August 1991.

Parasitoids

Source	df	MS	F Value	Pr
Block	1	5.208333	0.16	0.6896
Sugar	1	2970.075000	93.80	0.0001
Wheast	1	27.075000	0.86	0.3667
Sugar*Wheast	1	147.408333	4.66	0.0440
Error	19	31.664474		
Date	4	1193.841667	67.63	0.0001
Error(D*B)	4	11.333333		
D*S	4	219.200000	12.42	0.0001
D*W	4	48.450000	2.74	0.0344
D*S*W	4	26.658333	1.51	0.2077
Error	76	17.653509		

Table 3. Minute pirate bugs sampled 14-23 August 1991. Data analyzed using complete randomized block analysis of variance (RCB ANOVA) with repeated measures for number of minute pirate bugs collected per 15 sweeps from sugar, wheast, sugar*wheast or control plots, 14-23 August 1991.

Anthocorids

Source	df	MS	F Value	Pr
Block	1	53.333333	0.71	0.4097
Sugar	1	1470.000000	19.59	0.0003
Wheast	1	154.133333	2.05	0.1681
Sugar*Wheast	1	282.133333	3.76	0.0675
Error	19	75.045614		
Date	4	1913.812500	87.29	0.0001
Error(D*B)	4	30.979167		
D*S	4	226.270833	10.32	0.0001
D*W	4	43.445833	1.98	0.1058
D*S*W	4	100.737500	4.59	0.0022
Error	76	21.923904		

Table 4. Big-eyed bugs sampled 14-23 August 1991. Data analyzed using complete randomized block analysis of variance (RCB ANOVA) with repeated measures for number of big-eyed bugs collected per 15 sweeps from sugar, wheast, sugar*wheast or control plots, 14-23 August 1991.

Big-eyed Bugs

Source	df	MS	F Value	Pr
Block	1	22.533333	0.84	0.3698
Sugar	1	149.633333	5.60	0.0287
Wheast	1	2.133333	0.08	0.7805
Sugar*Wheast	1	38.533333	1.44	0.2444
Error	19	26.698547		
Date	4	84.925000	10.69	0.0001
Error(D*B)	4	12.741667		
D*S	4	23.716667	2.99	0.0240
D*W	4	5.633333	0.17	0.5880
D*S*W	4	9.991667	1.26	0.2939
Error	76	7.941667		

LEGENDS

Figure 1. Spatial arrangement of plots in Cache Valley, Utah, for artificial honeydew decay experiment in August, 1991. Treatments as described in text.

Figure 2. Average number of aphids per 15 sweeps in the control plots during experiment, 14-23 August 1991 (vertical bars indicate +/- one standard error).

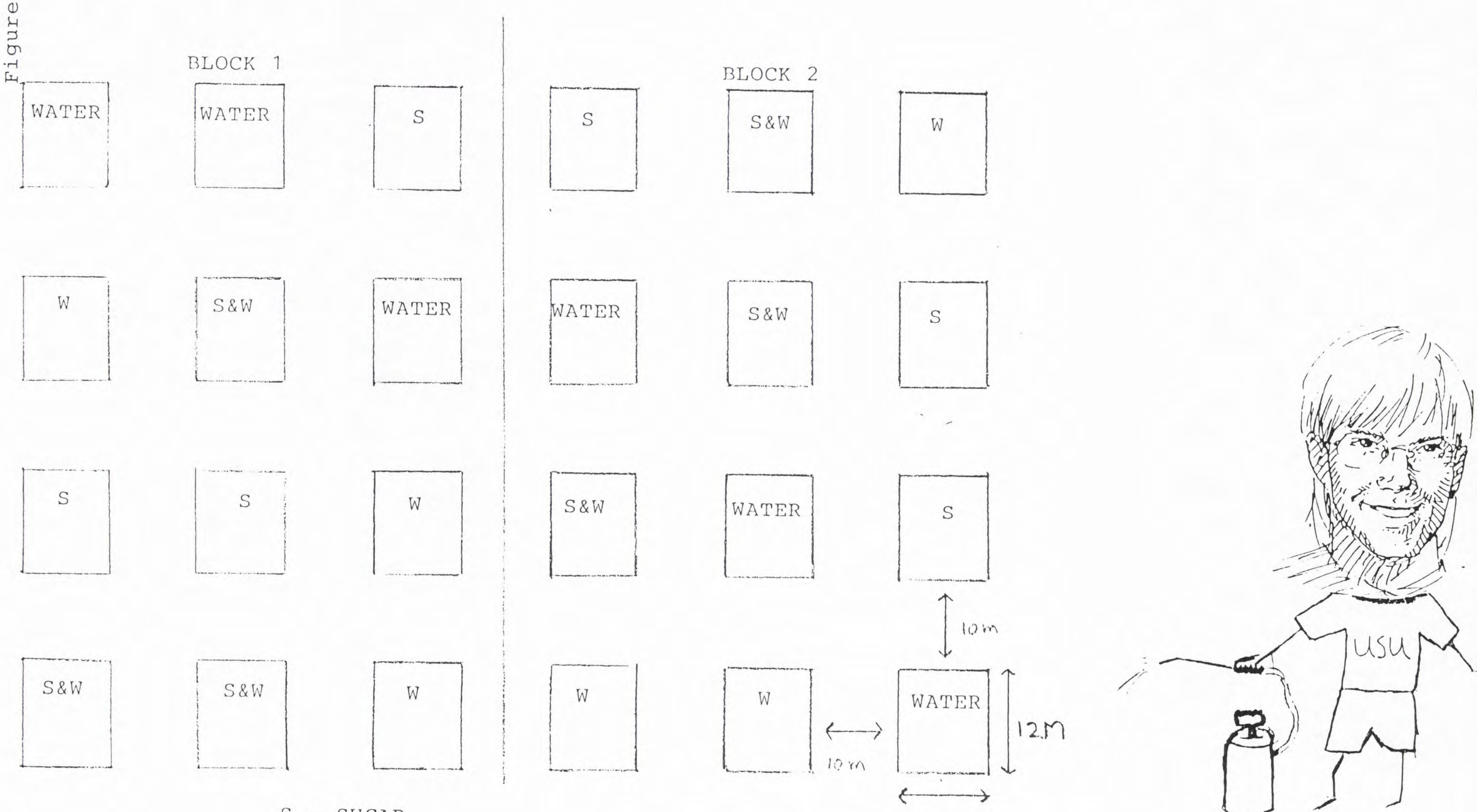
Figure 3. Interaction plots showing the response to sugar and wheast treatments of ladybeetles collected August 14-17. Data plotted as mean number of ladybeetles per 15 sweeps.

Figure 4. Response of parasitiods to treatments with/without sugar over time between 14-23 August 1991. Data plotted as mean number of parasitoids per 15 sweeps; means combined for plots with and without wheast.

Figure 5. Response of minute pirate bugs (Anthocorids) to treatments with/without sugar over time between 14-23 August 1991. Data plotted as mean number of minute pirate bugs per 15 sweeps; means combined for plots with and without wheast.

Figure 6. Response of big-eyed bugs to treatments with/without sugar over time between 14-23 August 1991. Data plotted as mean number of big-eyed bugs per 15 sweeps; means combined for plots with and without wheast.

Figure 1



S = SUGAR
W = WHEAST
S&W = SUGAR & WHEAST
WATER = WATER

NORTH

Figure 2

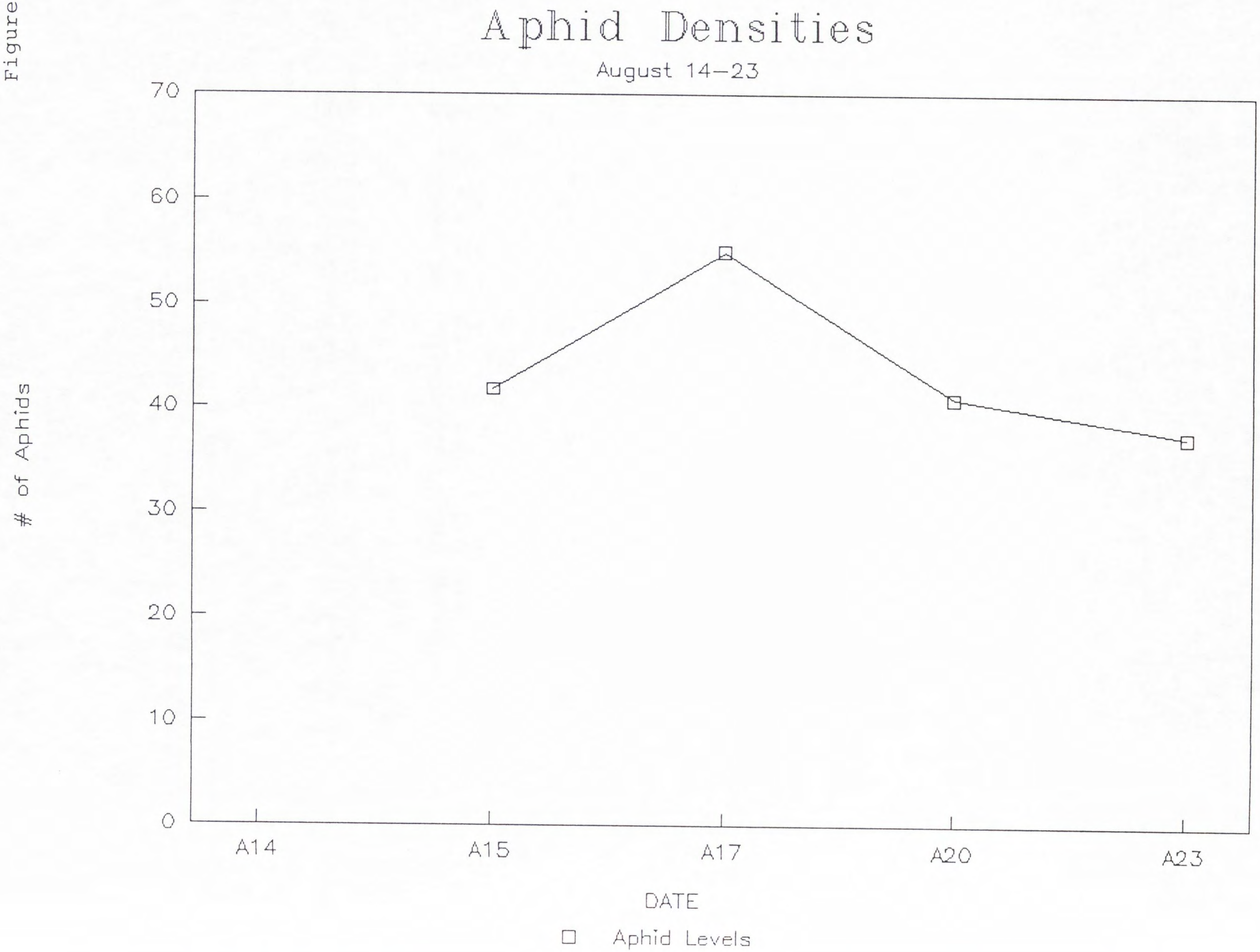

Aphid Densities
August 14–23
70
60
50
40
30
20
10
0
# of Aphids
A14
A15
A17
A20
A23
DATE
Aphid Levels

Figure 3

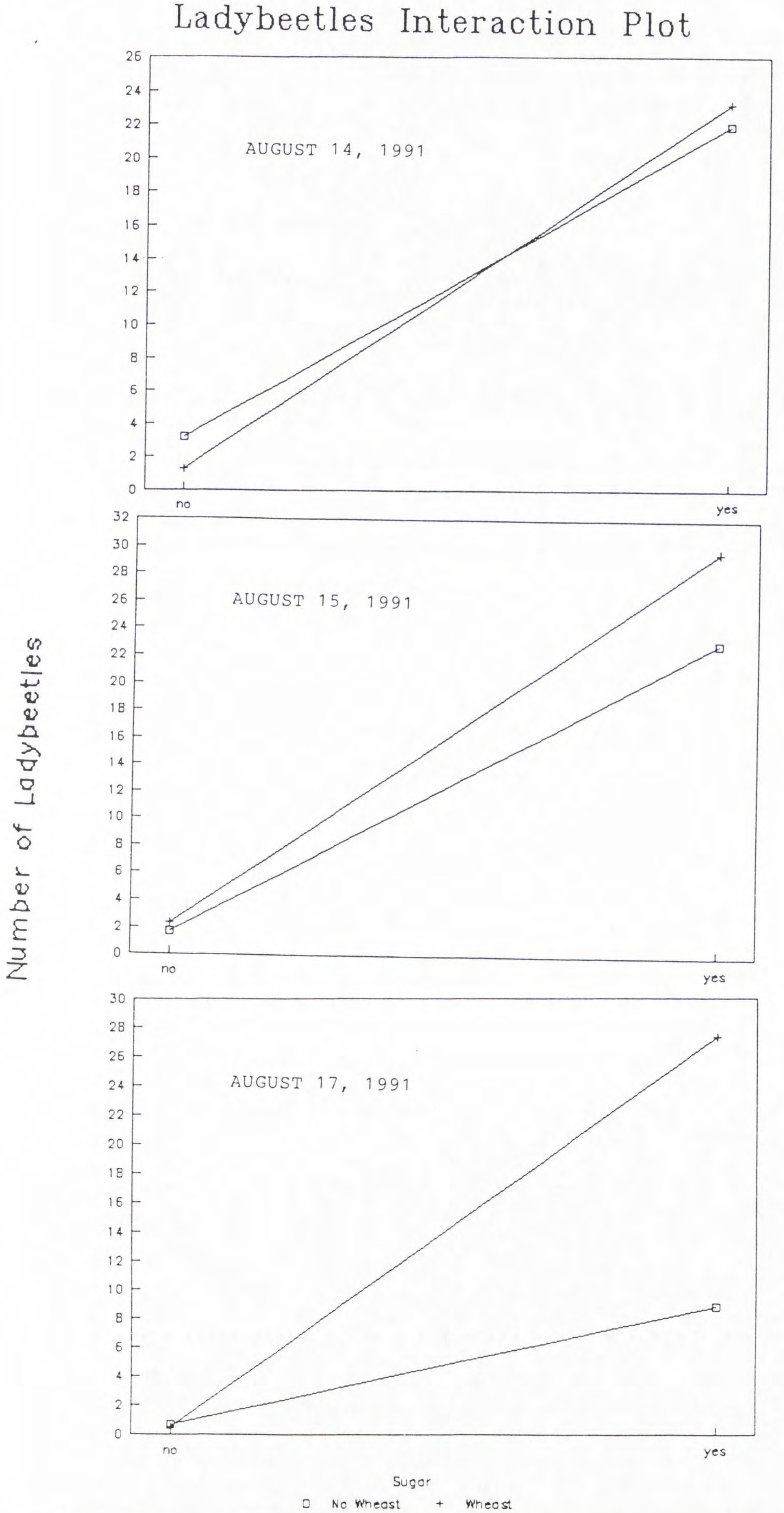

Ladybeetles Interaction Plot
Number of Ladybeetles
AUGUST 14, 1991
AUGUST 15, 1991
AUGUST 17, 1991
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
no
yes
Sugar
No Wheast
+ Wheast

Figure 4

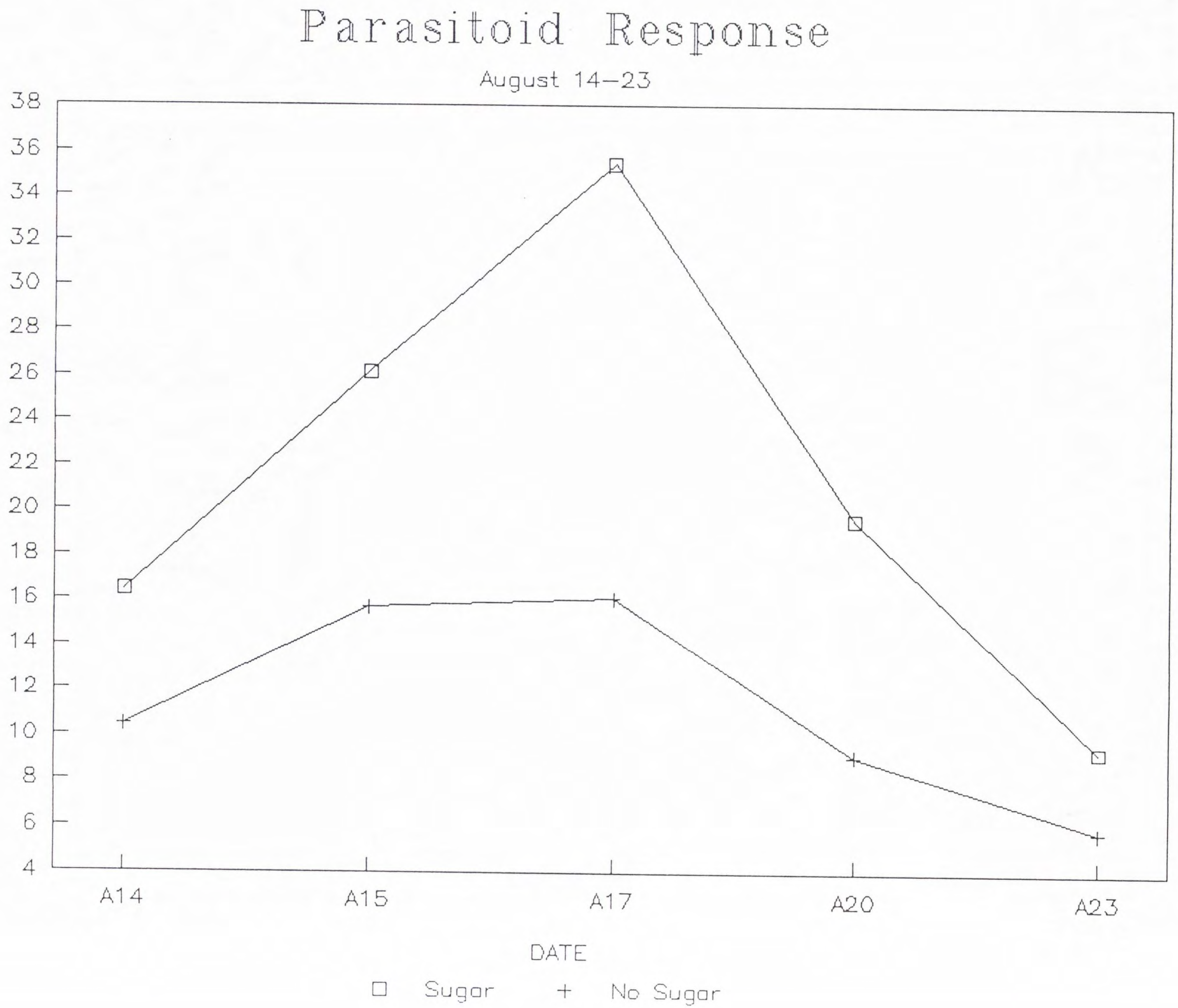

Parasitoid Response
August 14–23
# of Parasitoids
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
A14
A15
A17
A20
A23
DATE
Sugar
No Sugar

Figure 5

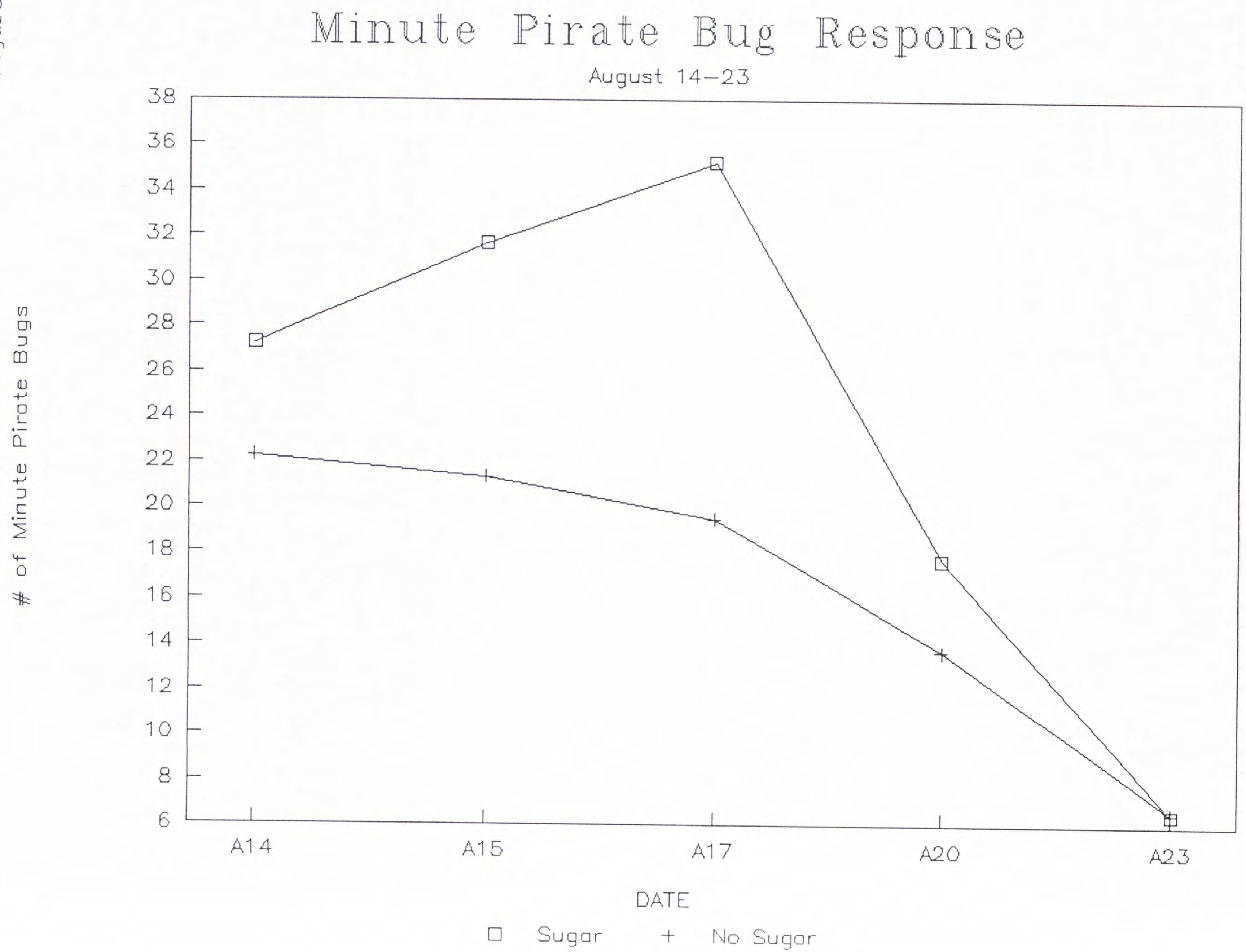
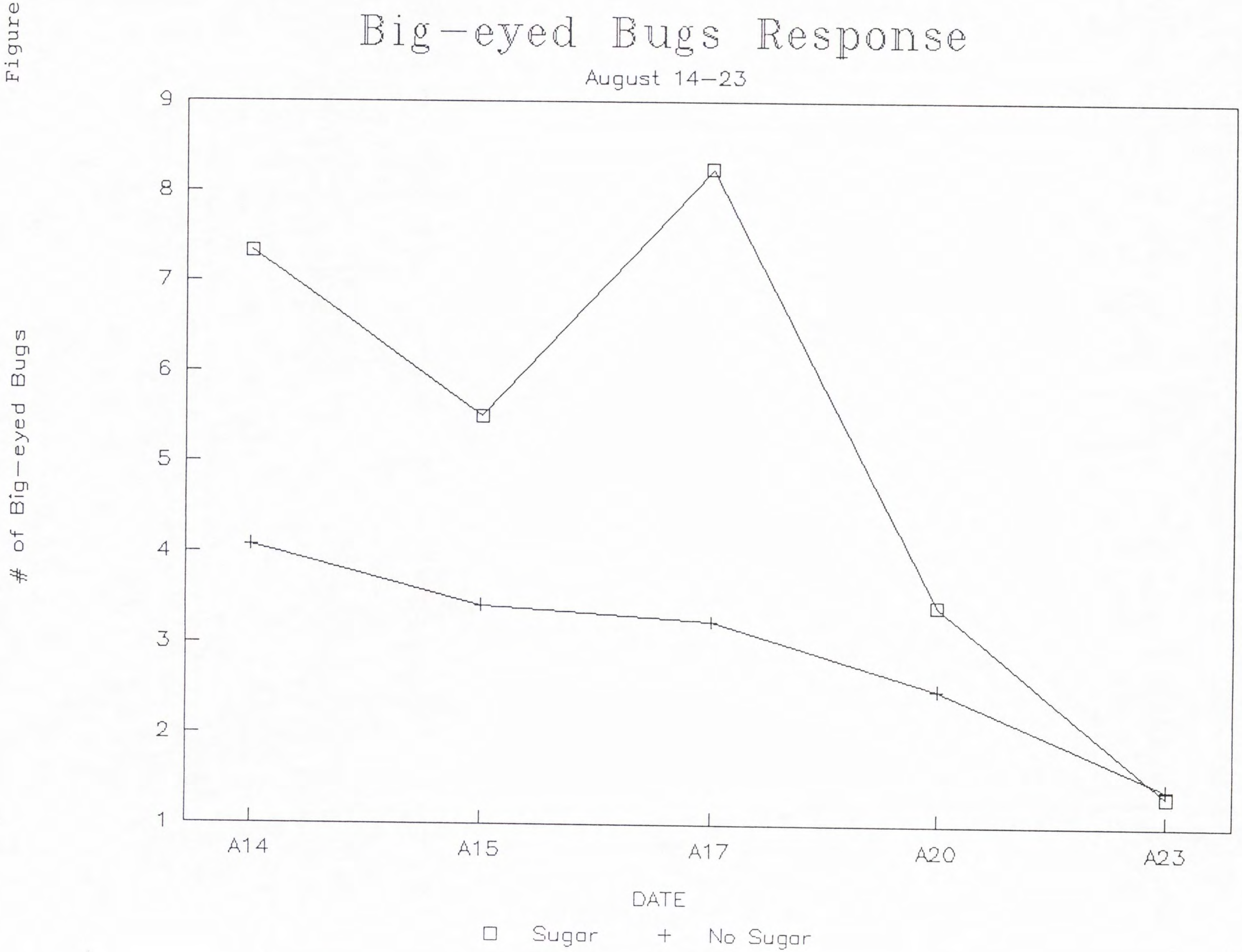

Minute Pirate Bug Response
August 14–23
# of Minute Pirate Bugs
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
A14
A15
A17
A20
A23
DATE
Sugar
No Sugar

Figure 6



Big-eyed Bugs Response
August 14-23
# of Big-eyed Bugs
9
8
7
6
5
4
3
2
1
A14
A15
A17
A20
A23
DATE
Sugar
No Sugar